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The Evaluation of Fractal Surfaces for Modeling Radar Backgrounds

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ABSTRACT

We evaluate how well fractals match the radar backscatter of natural backgrounds in terms of dependence on angle of incidence. We discuss the parameters that define the particular surfaces studied. Finally, we compare the radar backscatter from a range of fractals to experimental backscatter data from natural backgrounds, and we discuss the suitability of fractal surfaces as modeling surrogates for the still more complex natural backgrounds.

INTRODUCTION

In a previous paper [1], we examined the use of Gaussian surfaces of uniform triangular facets to model the radar backscatter properties of natural backgrounds. We studied the radar scattering properties of backgrounds because backgrounds play key roles in the design of low signature ground vehicles. First, overall backscatter from the background can determine the required signature level of the vehicle. And, second, through multipath, reflections from the ground can influence the apparent signature of the vehicle. We, however, concluded that the backscatter cross sections of these modeled backgrounds did not match experimental data well enough for quantitative use. In this paper, we extend this work by studying the radar backscatter of more complex surfaces, namely, fractal surfaces [2], [3].

PREVIOUS RESULTS

Figures 1 and 2 summarize our previous results of using a Gaussian surface to model backgrounds. Experimental backscatter data [4 and 5] show less dependence on angle of incidence than the Gaussian surface.

FRACTALS

Successful in rendering the appearance of such natural phenomena as clouds and mountain ranges, fractals offer the possibility of matching the radar backscatter properties of natural backgrounds.

What is a fractal? Musgrave's definition [2] states that a fractal is "a geometrically complex object, the complexity of which arises through the repetition of form over some range of scale". Here, "form" refers to the basis function used in generation of the fractal. For example, a fractal could be created by repeatedly scaling and adding a sine wave.

As Musgrave says, "Fractal models are sometimes assailed on the grounds that they lack a physical basis in reality." For example, the creation and erosion of mountains is not necessarily fractal in its physical processes, yet fractals do an excellent job of modeling mountains, at least aesthetically.

Unfortunately, this lack of a physical basis means that the input parameters used when generating a fractal terrain must be found by trial and error. The input parameters used by our fractal generation code are:

- H – roughness parameter, also known as the Hurst parameter
- to 1.0, 1.0 being the most smooth

- Lac - lacunarity – the change in frequency with each octave added in, a value of 2.0 is typically used, denoting a doubling of frequency with each additional octave

- Oct - number of octaves – the number of frequencies combined in generating the fractal. As Oct is increased, the resolution of the mesh must be increased to retain the added detail.

- VSF - vertical scale factor, the overall height controlling factor. A value of 10.0 results in a fractal mesh with an approximate range of –5.0 to 5.0.

Figures 3 through 8 show the parameters used to create the seven meshes studied. Moreover, these figures illustrate the effects of changing these parameters from the default values.

The code also requires some nonfractal input parameters, Figure 9. The mesh resolution sets the number of squares on a side of the mesh. We created meshes with a resolution of 100 by 100. Since each square yields two triangle facets, each mesh contained 20,000 facets. The Xpatch material number was set to 0, corresponding to a perfect electrical conductor. For basis functions, we selected noise functions. A checkbox allows the option of setting all negative values to 0. Such a mesh has the appearance of a flat plane with fractal feature rising out of it.

Using the core fractal code from Ebert et al [3], one of us (Evans) created the mesh generator. A key addition was in the output files. The mesh generator has the ability to create a mesh for output to .raw or .facet (Xpatch) formats. The .raw format is used for input into the Windows program Rhinoceros, a 3-D geometry creation and viewing program. The fractal code used is based on Perlin's noise basis function. We also plan to experiment with other basis functions for comparison. The core fractal code is written in the C programming language, and all other code is in object-oriented C++. The program was compiled with Borland C++ Builder version 4. Figure 9 shows that the program is an easy-to-use, GUI (graphical user interface) program.

We anticipate uses for this fractal terrain generation tool other than Xpatch modeling. The terrains generated should be better than perfectly flat ground planes for thermal and visual modeling. For radar modeling, vehicle geometries are easily added to the terrain mesh, Figure 10 shows the DTANK geometry combined with a fractal ground plane.

BACKSCATTER OF FRACTALS

Figure 11 compares the 35 GHz, Vertical-Vertical, backscatter from the modeled backgrounds with experimental backscatter data. Meshes 1, 3, 5, 6 and 7 all performed better than the Gaussian model. Meshes 2 and 4 exhibited worse performance than the Gaussian model. Mesh 3 produced the best match to the experimental data.

Figure 12 plots the results for Mesh 3, the Gaussian model and several natural backgrounds. This plot shows that Mesh 3 matches the natural backgrounds in dependence on angle of incidence. Comparison with the results for Meshes 2 and 4 shows that adjustment of the roughness or vertical scale factor might further improve the fit.

CONCLUSIONS

In comparison to Gaussian surfaces, fractal surfaces are better matches to experimental backgrounds in dependence on angle of incidence.

We recommend additional exploration of fractal parameters to improve the match between fractals and experimental backgrounds. Moreover, additional basis functions should be studied for generating fractal backgrounds.

REFERENCES

[1] Bennett, J.G., Evans, R. and Jones, J.; "Modeling Backgrounds for the Prediction of the Radar Signatures of Ground Vehicles"; Proceedings of the 2000 Meeting of the MSS Specialty Group on Camouflage, Concealment & Deception, Charleston, SC; 2000.

[2] Ebert, D., Musgrave, F.K., Peachey, D., Perlin, K., Worley, S., *Texturing and Modeling, a Procedural Approach*, Academic Press, 1998.

[3] Peitgen, H., Jurgens, H., Saupe, D., *Fractals for the Classroom*, Part One: Introduction to Fractals and Chaos, Springer-Verlag, 1992.

[4] F.T. Ulaby and T.F. Haddock, University of Michigan, 1990.

[5] W.H. Peake and T.L. Oliver, Ohio State University, 1971.

Modeled vs. Experimental Backscatter

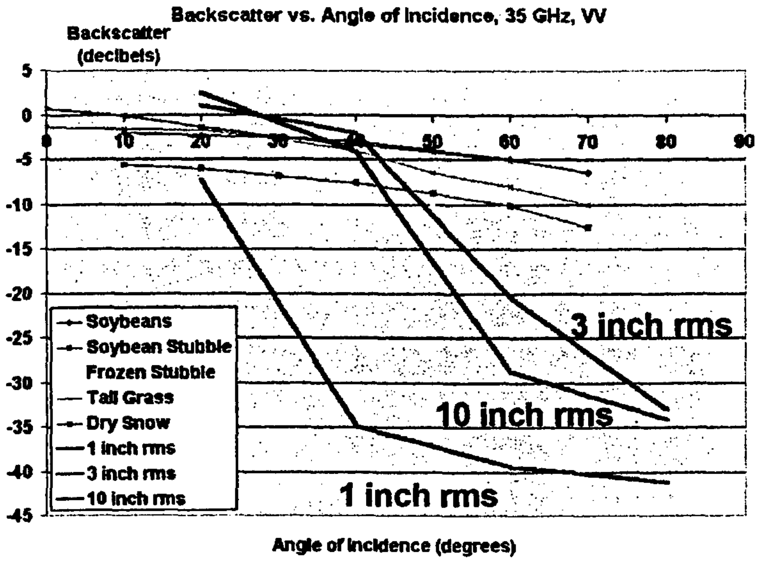


Figure 1 Backscatter versus angleof incidence for Gaussian surfaces.

Modeled vs. Experimental Backscatter

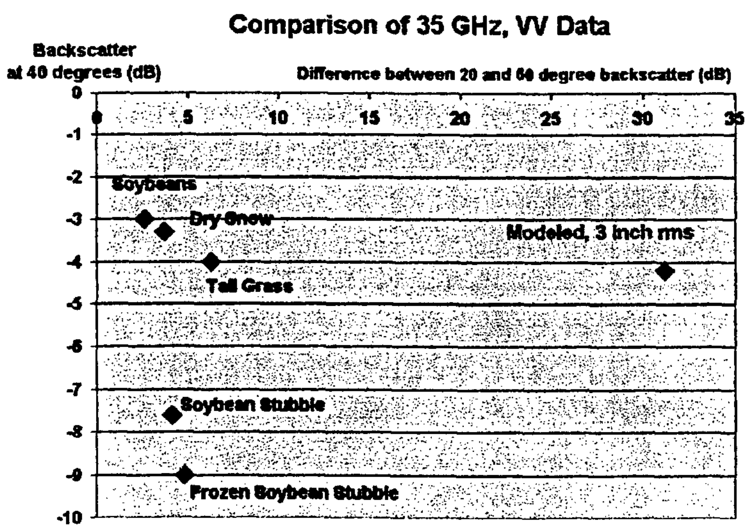
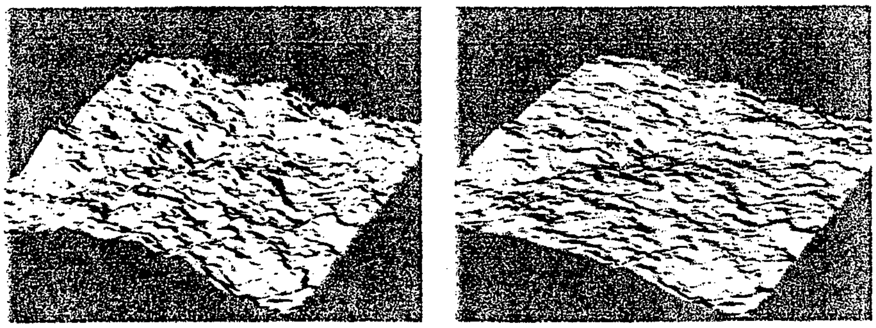


Figure 2. Backscatter performance of Gaussian surface.

Parameters of fractal surfaces

Default, Mesh 1 | Mesh 2

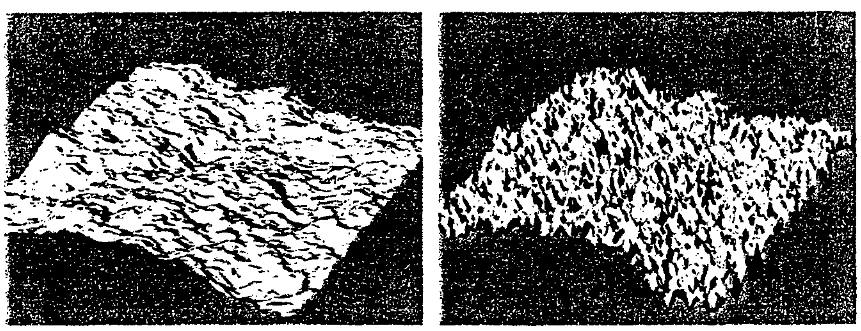


	Default, Mesh 1	Mesh 2
H	0.7	0.7
Lac	2	2
Oct	10	10
VSF	10	5

Figure 3. A comparison of Mesh 2 and the default Mesh 1.

Parameters of fractal surfaces

Default, Mesh 1 | Mesh 3

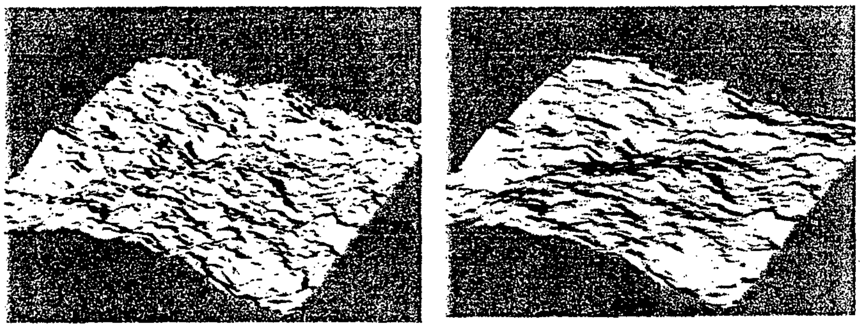


	Default, Mesh 1	Mesh 3
H	0.7	0.3
Lac	2	2
Oct	10	10
VSF	10	10

Figure 4. A comparison of Mesh 3 and the default Mesh 1.

Parameters of fractal surfaces

Default, Mesh 1 | Mesh 4

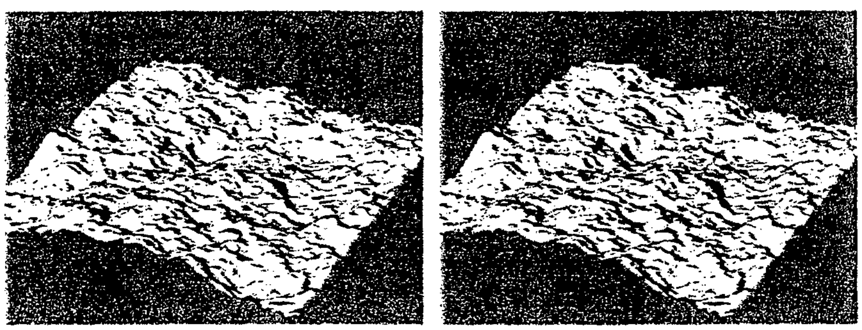


	Default, Mesh 1	Mesh 4
H	0.7	0.9
Lac	2	2
Oct	10	10
VSF	10	10

Figure 5. A comparison of Mesh 4 and the default Mesh 1.

Parameters of fractal surfaces

Default, Mesh 1 | Mesh 5

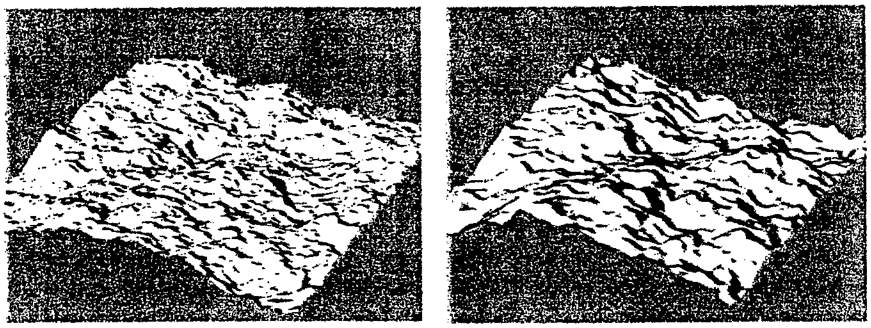


	Default, Mesh 1	Mesh 5
H	0.7	0.7
Lac	2	2
Oct	10	14
VSF	10	10

Figure 6. A comparison of Mesh 5 and the default Mesh 1.

Parameters of fractal surfaces

Default, Mesh 1 Mesh6

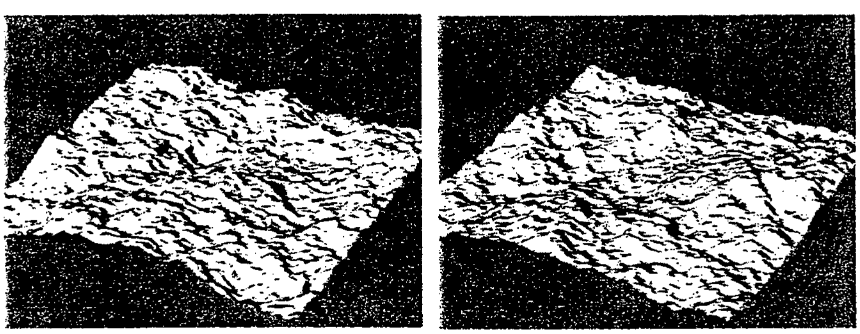


H	0.7	0.7
Lac	2	1.5
Oct	10	10
VSF	10	10

Figure 7. A comparison of Mesh 6 and the default Mesh 1.

Parameters of fractal surfaces

Default, Mesh 1 Mesh 7



H	0.7	0.7
Lac	2	2.5
Oct	10	10
VSF	10	10

Figure 8. A comparison of Mesh 7 and the default Mesh 1.

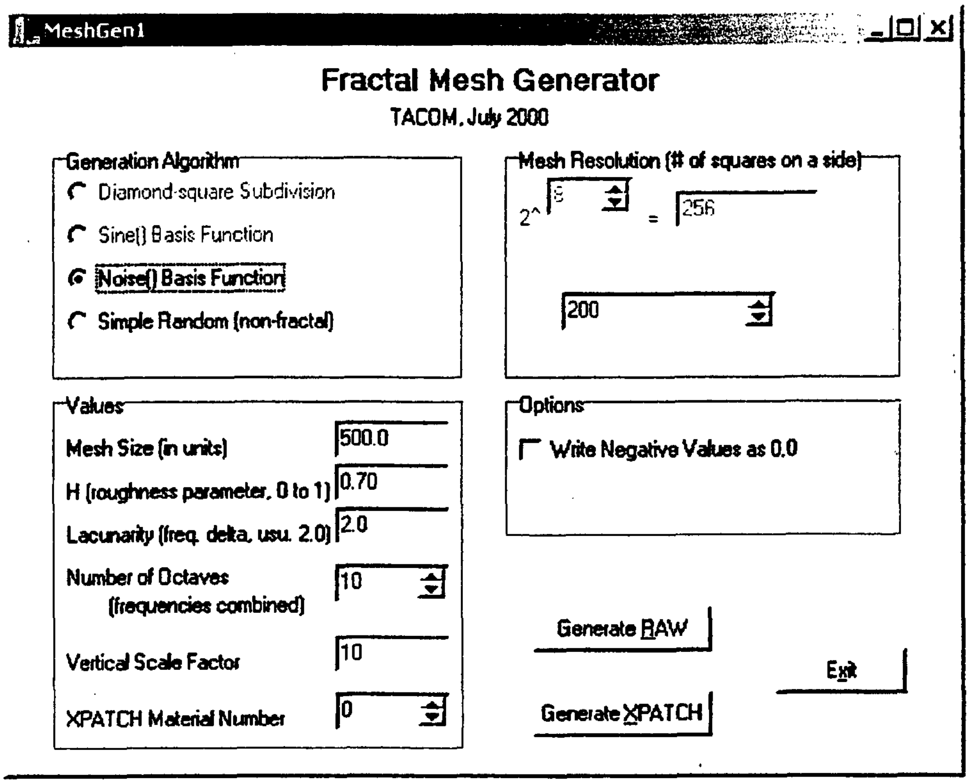


Figure 9. Input screen for fractal generator.

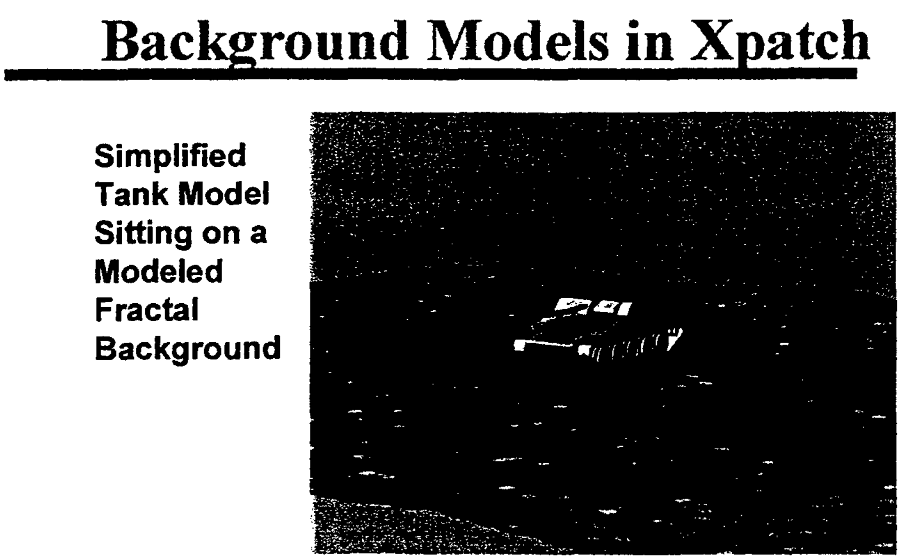


Figure 10. A tank sitting on a fractal background.

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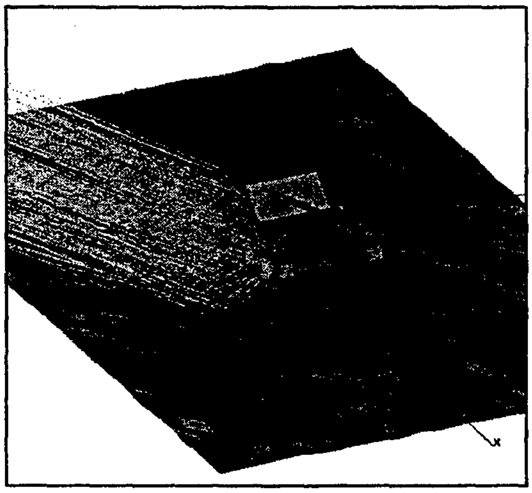
Summary

- The Problem
  - Selecting parameters of background models in Xpatch
- Previous work on background models in Xpatch
- Fractal parameters and surfaces
- Results of backscatter predictions
- Recommendations and conclusions

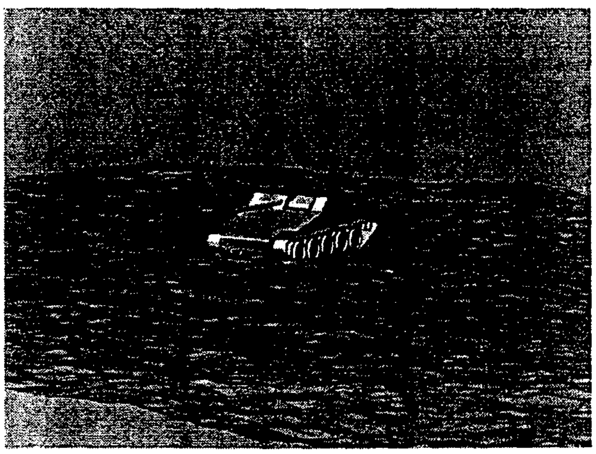
Background Models in Xpatch

Simplified Tank Model Sitting on a Modeled Gaussian Background

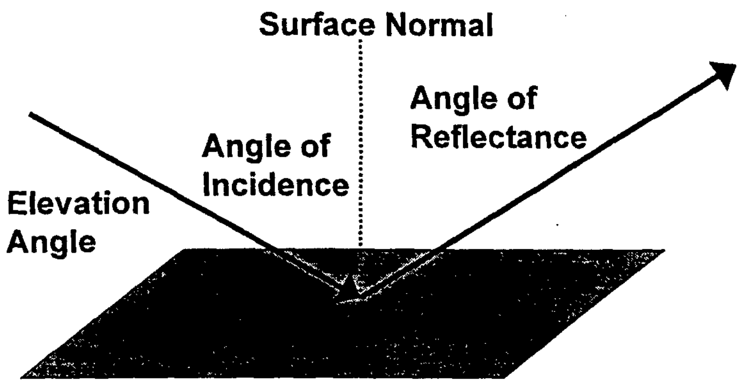


Background Models in Xpatch

Simplified Tank Model Sitting on a Modeled Fractal Background



Scattering Definitions



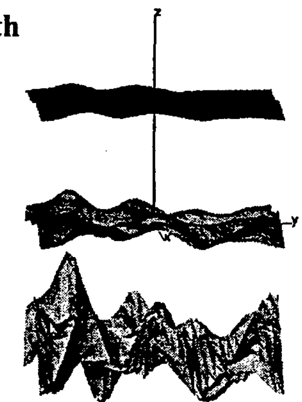
$$\text{Backscatter} = \frac{\text{RCS of Surface}}{\text{Area of Surface}}$$

Prediction of Background RCS

- Used Xpatch 2.4 on a Silicon Graphics Indigo computer with default Xpatchf parameters
- Predicted RCS for 18 azimuth angles and averaged values

Parameters of Xpatch Gaussian Backgrounds

Correlation Length	RMS Height
10 in.	1 in.
10 in.	3 in.
10 in.	10 in.

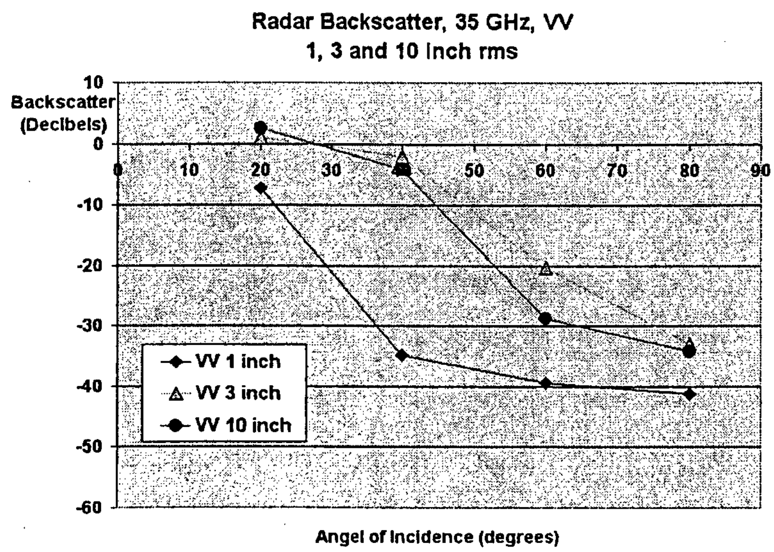


Area = 100 in. x 100 in.

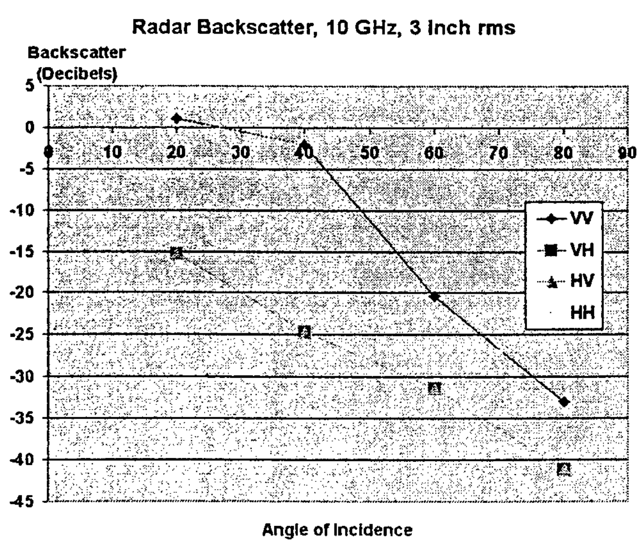
Material = Perfect Conductor

Predicted Backscatter of Modeled Backgrounds

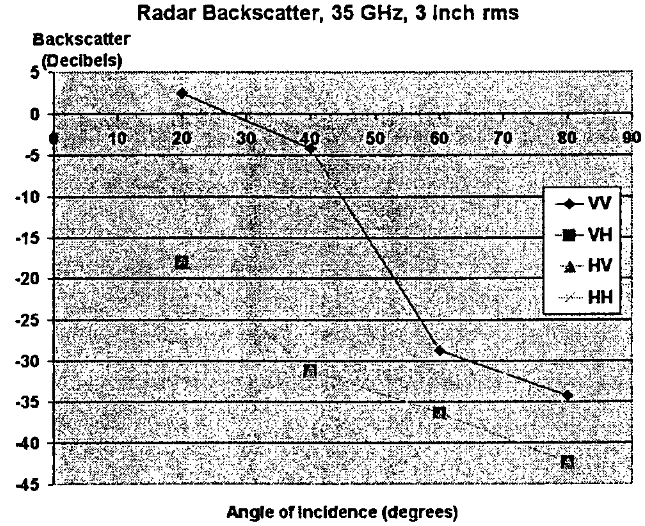
Backscatter vs. RMS



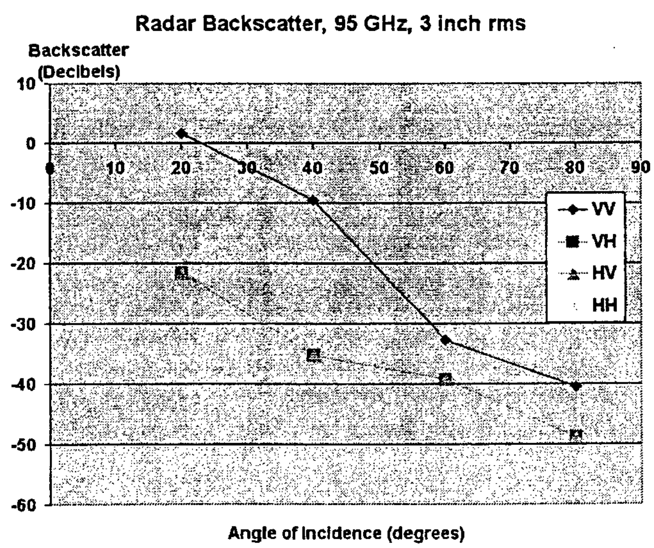
Modeled, 10 GHz 3 inch rms



Modeled, 35 GHz 3 inch rms



Modeled, 95 GHz 3 inch rms

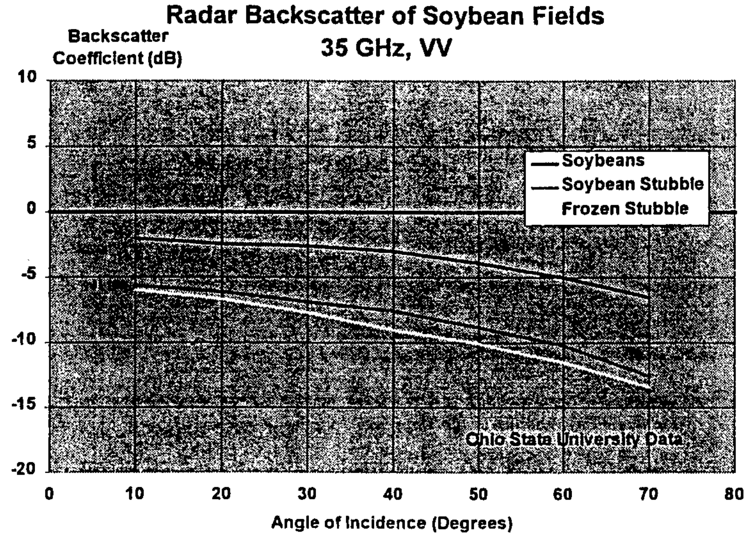


Measured Backscatter of Natural Backgrounds

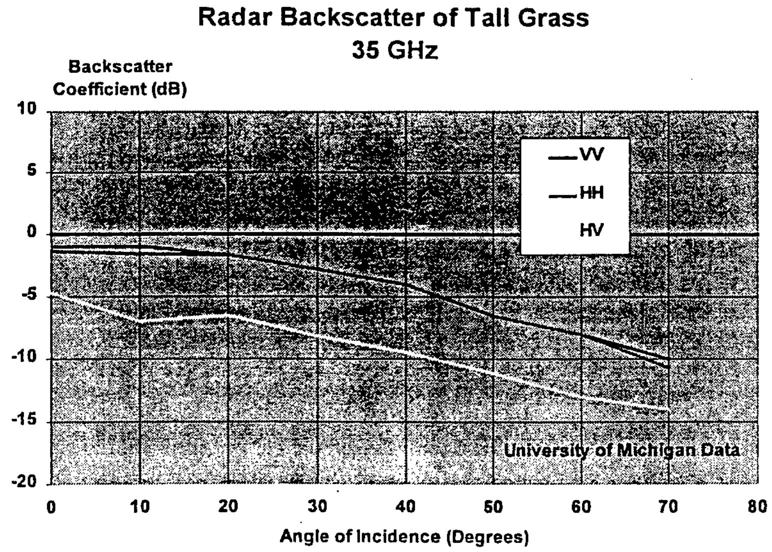
Experimental Terrain Data

- Sources:
  - —F.T. Ulaby and T.F. Haddock, University of Michigan, 1990.
  - —W/H. Peake and T.L. Oliver, Ohio State University, 1971.

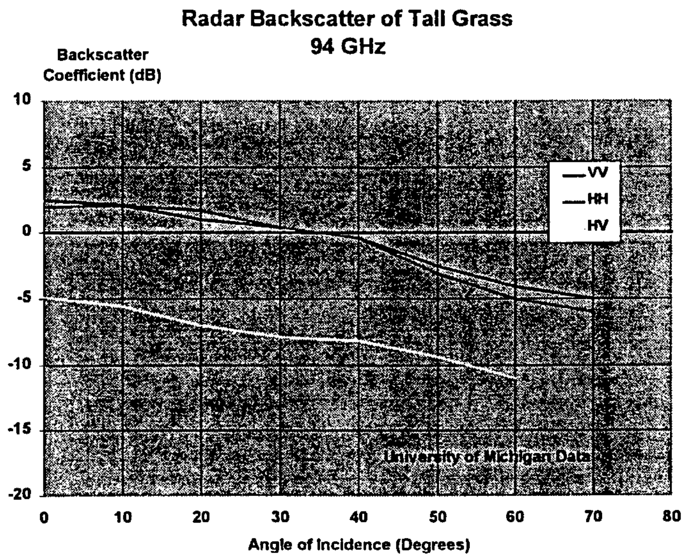
Backscatter from Soybeans



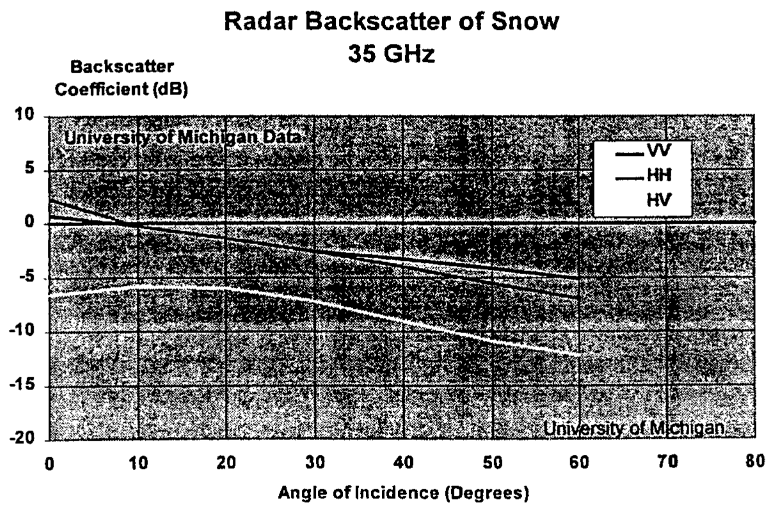
Backscatter from Tall Grass, 35 GHz



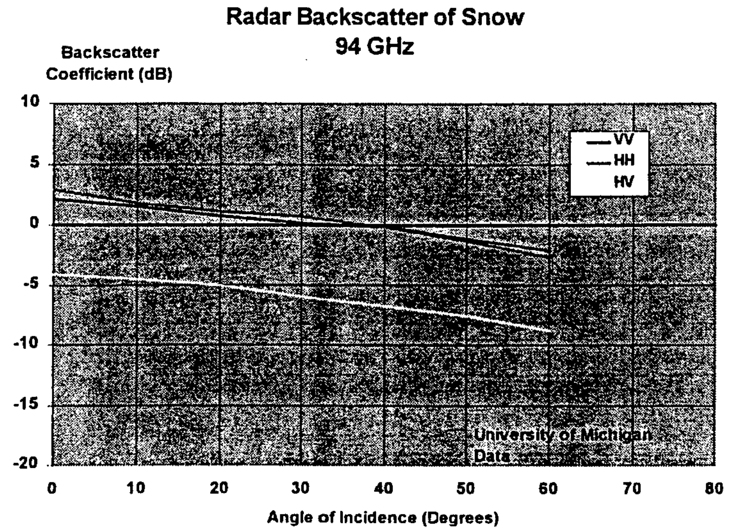
Backscatter from Tall Grass, 94 GHz



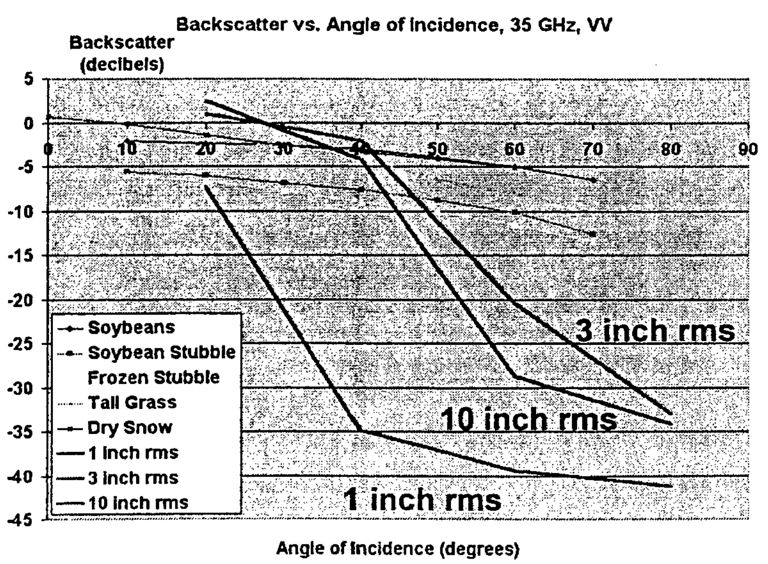
Backscatter from Dry Snow, 35 GHz



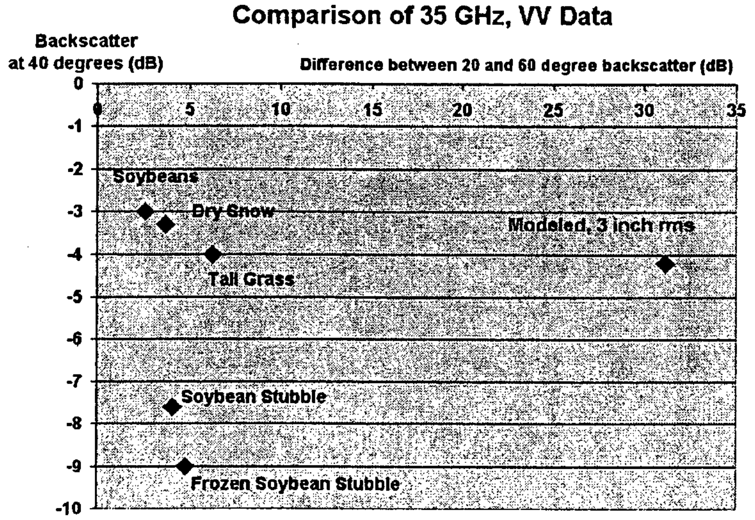
Backscatter from Dry Snow, 94 GHz



Modeled vs. Experimental Backscatter



Modeled vs. Experimental Backscatter



Fractal Surfaces

References on Fractals

- Ebert, D., Musgrave, F.K., Peachey, D., Perlin, K., Worley, S., Texturing and Modeling, a Procedural Approach, Academic Press, 1998.
- Peitgen, H., Jurgens, H., Saupe, D., Fractals for the Classroom, Part One: Introduction to Fractals and Chaos, Springer-Verlag, 1992.

Fractals

- Musgrave's definition: "a geometrically complex object, the complexity of which arises through the repetition of form over some range of scale."
- The form is the basis function, for example, sine waves.

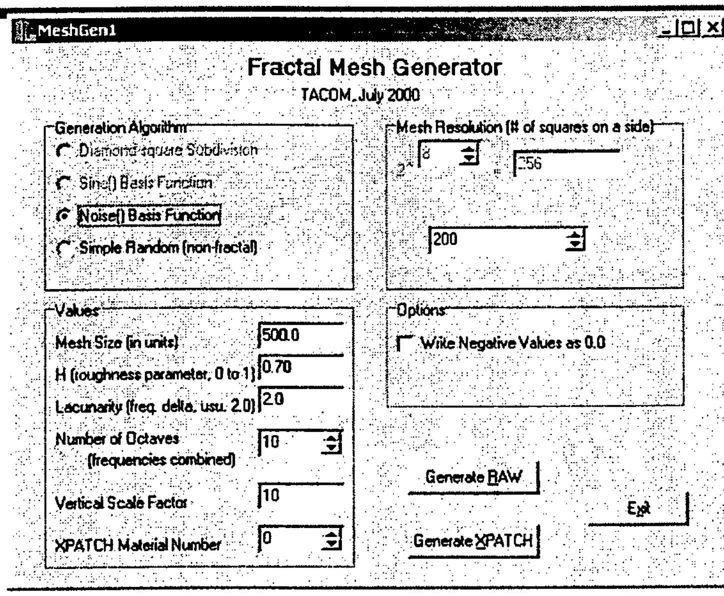
Fractal Parameters

- H – roughness parameter, also known as the Hurst parameter, 0.0 to 1.0, with 1.0 being the most smooth
- L -lacunarity, the change in frequency with each octave added in, a value of 2.0 is typically used, denoting a doubling of frequency with each additional octave.

Fractal Parameters

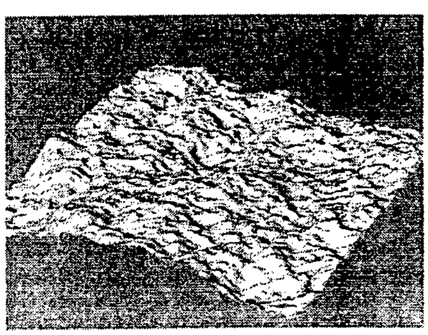
- Oct - number of octaves – the number of frequencies combined in generating the fractal.
- VSF - vertical scale factor, a factor that controls the range of heights.

Fractal Mesh Generator

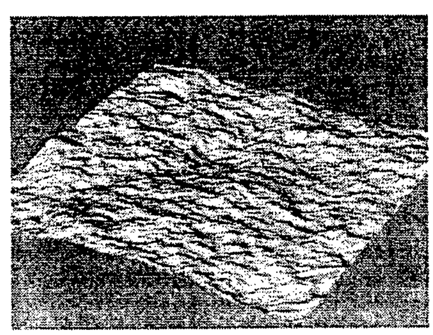


Parameters of fractal surfaces

Default, Mesh 1

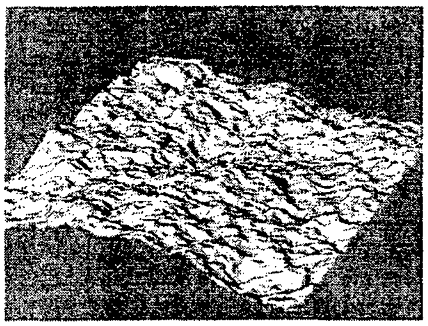
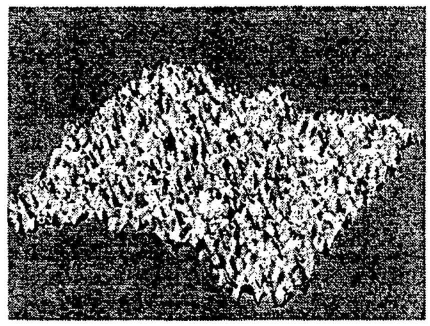


Mesh 2



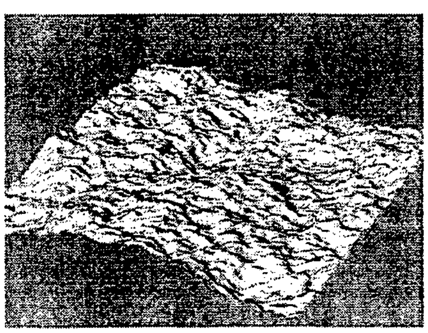
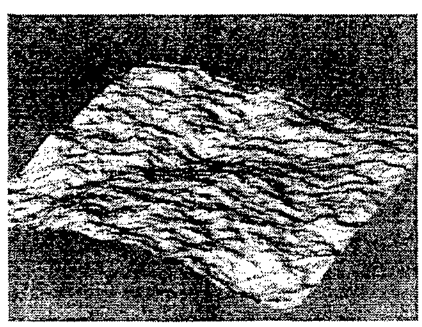
	Default, Mesh 1	Mesh 2
H	0.7	0.7
Lac	2	2
Oct	10	10
VSF	10	5

Parameters of fractal surfaces

Default, Mesh 1	Mesh 3
	

	Default, Mesh 1	Mesh 3
H	0.7	0.3
Lac	2	2
Oct	10	10
VSF	10	10

Parameters of fractal surfaces

Default, Mesh 1	Mesh 4
	

	Default, Mesh 1	Mesh 4
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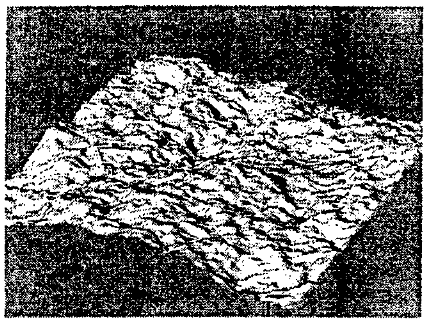
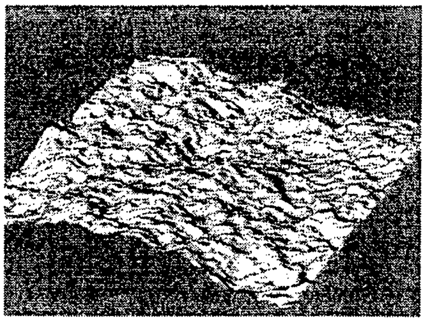
Lac	2	2
Oct	10	10
VSF	10	10

Parameters of fractal surfaces

Default, Mesh 1 | Mesh 5

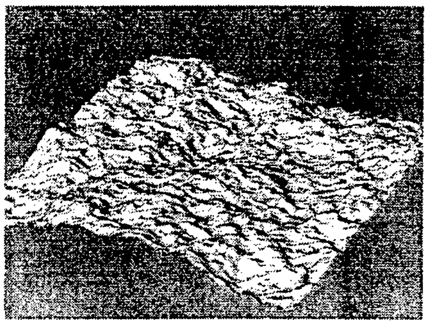


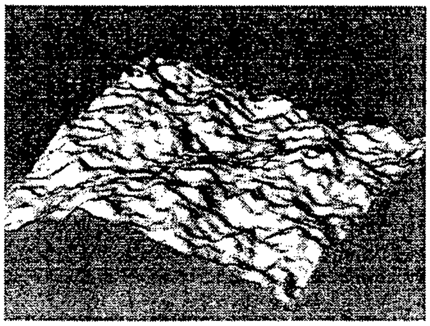


	Default, Mesh 1	Mesh 5
H	0.7	0.7
Lac	2	2
Oct	10	14
VSF	10	10

Parameters of fractal surfaces

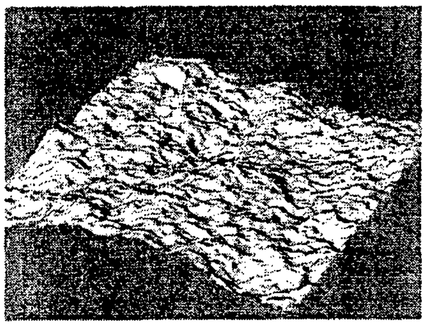
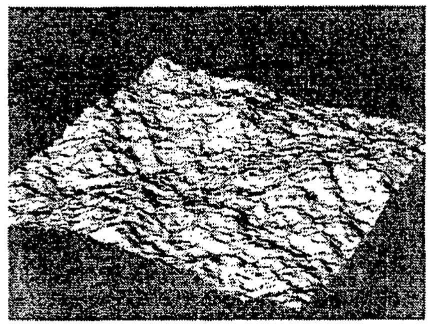
Default, Mesh 1 | Mesh6





	Default, Mesh 1	Mesh6
H	0.7	0.7
Lac	2	1.5
Oct	10	10
VSF	10	10

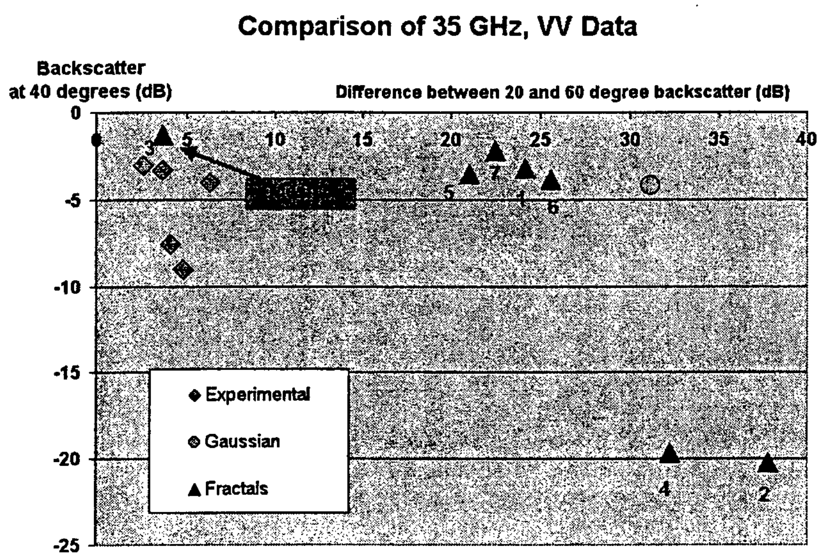
Parameters of fractal surfaces

Default, Mesh 1	Mesh 7
	

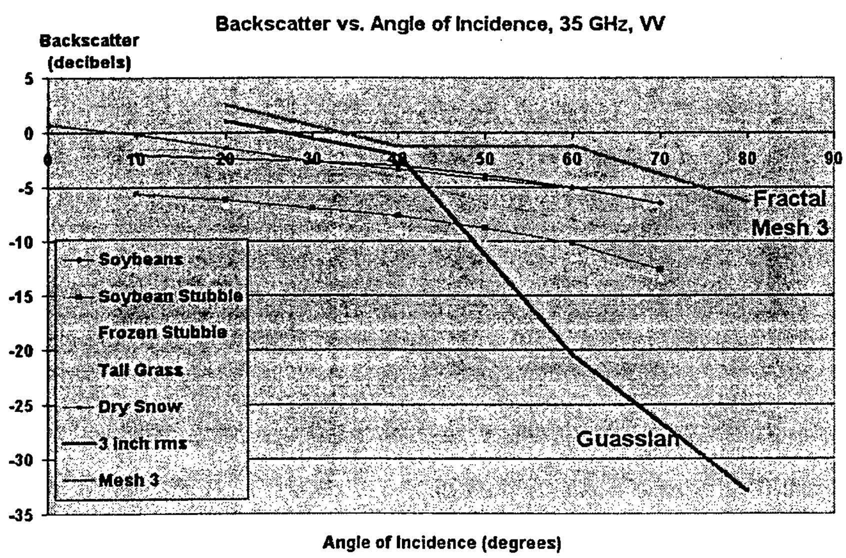
	Default, Mesh 1	Mesh 7
H	0.7	0.7
Lac	2	2.5
Oct	10	10
VSF	10	10

Comparison Between Natural and Fractal Backgrounds

Modeled vs. Experimental Backscatter



Modeled vs. Experimental Backscatter



Conclusions

- Fractal surfaces are better matches to experimental backgrounds in general dependence on angle of incidence than are Gaussian surfaces.
- We recommend additional exploration of fractal parameters to improve the match between fractals and experimental backgrounds.

16244

OPSEC REVIEW CERTIFICATION

(AR 530-1, Operations Security)

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Name Grade Title
Wallace R. Mick Jr. 11 Aug 2000
Signature Date

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Author/Originator(s): Roger Evans, John Bennett and Jack Jones

Publication/Presentation/Release Date: 16 August 2000

Purpose of Release: To participate in TACOM sponsored Ground Target Modeling and Validation Conference

An abstract, summary, or copy of the information reviewed is available for review.

Reviewer's Determination (check one) The paper deals with background radar models of fractal terrain roughness. This is clearly unclassified because no military information is covered and unlimited release is recommended. Wally Mick

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